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TERRACES OF THE WEST RIVER, BRATTLEBORO, VERMONT.

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No. 2.— TERRACES OF THE WEST RIVER, BRATTLEBORO, VERMONT.

BY E. F. FISHER.

Introduction.

The flights of stepping terraces which border our New England rivers are of singular interest and add much to the beauty and charm of the river topography. The almost level terrace plains and especially the low-lying meadows are agriculturally the most fertile in New England. They represent river-deposited and carved remnants of the clays, sands, and gravels which once occupied in larger volume than to-day the rock-floored valleys of still earlier origin. They are but transitory waste forms on the way to the sea. The meadows, irrigated each year by the floods and hence the richest of these terrace plains, are steadily increasing or decreasing in extent as attacked by the river, and all the time some of the flood plain is being washed down the valley toward the sea.

The river terraces of New England may be accounted for by the behavior of meandering and swinging streams slowly degrading previously aggraded valleys without necessary change in volume and by the control exerted here and there over the lateral swinging of the streams through the discovery of rock ledges. The rivers are essentially graded, with reference to sea level, to the main stream or to a local rock barrier, though all the while actively swinging, slowly degrading streams. Prof. W. M. Davis has most ably stated and discussed this river-terrace theory and its deduced consequences, defining terraces in early, middle, and late stages, and also the various patterns produced by free-swinging rivers constrained by rock barriers.

The purpose of this investigation is to test the above theory by applying it to a new locality. As a whole, the theory stands. A few modifications of special features are suggested. The West River in Vermont, at its junction with the Connecticut at Brattleboro, was chosen as offering varied and distinct illustration of numerous terrace patterns and as showing the importance of rock barriers. Furthermore, the valley of this West River is narrow and can be studied

within a limited area, as the river in its wandering and degrading discovered a large number of rock ledges which defend the higher and older terraces and prevent their erosion.

In consideration of the variety of terrace forms developed by the West River, it seemed advisable to survey with transit and stadia an area covering about two square miles at the junction of the West and Connecticut Rivers. The area surveyed was plotted on the scale of four hundred feet to the inch. Terrace scarps have been hachured and the different levels of the plains noted by heights (in feet) above mean sea level, and in groups by shading. The map (pl. 1) reveals the destructive postglacial work of the West River in the constructive postglacial filling of its valley.

Another portion of the field work has been the measuring, with a Locke level, of terrace scarps here and there (at frequent distances) for about two hundred miles along the Connecticut River from Saybrook to Brattleboro. From such measurements taken in different sections of the valley, it may be possible to determine by means of their variations whether an even regional uplift or a tilting was chiefly responsible for the activity of the river in degrading its valley. Such dimensions will give direct proof as to the kind of movement by which the process of terracing was initiated, and will possibly confirm the evidence already at hand regarding the nature of postglacial movement in New England. The results of this portion of the field work will be presented at another time.

For valuable suggestion and advice in this study the writer gratefully acknowledges indebtedness to Prof. W. M. Davis, and also takes the present opportunity of thanking Dr. S. E. Lawton of Brattleboro, Vt., for unfailing kindness in the furtherance of the field work.

Preliminary Inquiry.

Terraces in the cycle.— A typical section of one of the terraced river valleys in New England (represented in the accompanying text-figure A) shows a broad rock valley, aggraded with drift, and partially degraded by a swinging river checked in its lateral cutting here and there by the discovery of rock ledges. These ledges act as barriers against which the river is practically powerless. The river terraces are deposits of stratified sands and gravels temporarily delayed on their way to the

sea, and indicate an interruption in the cycle of river development. The rock valleys represent the work accomplished, before the ice age, by the mature rivers in sculpturing our hills and valleys.

During the glacial period, the valleys became filled with abundant drift material, and the subsequent changes of level in the earth's surface forced the rivers to erode, stratify, and carve the unconsolidated material into the form of terraces. Postglacial time has allowed the rivers to swing widely in their valleys and thus remove more and more of the unconsolidated material, a task which is as yet very incomplete because of the rock ledges, which have served as barriers, preventing erosion and so protecting the higher alluvial plains. Should the rivers succeed in removing all the valley drift,— or in cutting down to the floor of the preglacial rock valleys,— they would not have advanced beyond the preglacial stage of their cycle of development. Davis ('02, p. 285) has clearly shown that "terraces are examples of the forms assumed by waste that still remains in its stopping-place after part of its volume has been swept forward again."

Terrace pattern.— A river terrace is a plain terminated backward by an escarpment which rises to the terrace above, and forward by

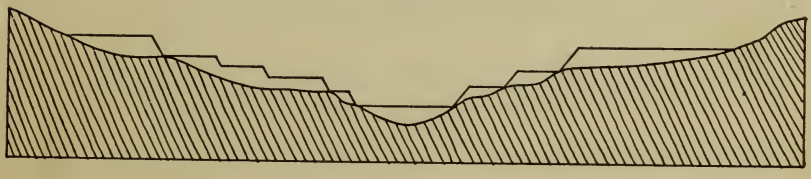


FIG. A.— Typical section of a terraced river valley in New England. Shows a broad rock valley, aggraded with drift and partially degraded by a swinging river checked in its lateral cutting here and there by the discovery of rock ledges.

an escarpment which falls to the terrace below. The surface of a terrace is rarely level, but slopes gently toward the sea, since it has been deposited by the gradually falling river. Further, the terrace floor slopes toward its river bed as an even or as an undulating surface. Occasionally the plain rises toward its river on account of accumulations from heavy floods.

The most significant line of the terrace is not the conspicuous front edge where the plain drops by an escarpment to a lower terrace, but rather, the line to the back and at the base of the rising escarp-

ment, since this line is determined by the carving action of the stream, while the conspicuous frontal edge of the terrace has oftentimes been affected by the simple processes of drainage. A characteristic feature of some terraces is a line of drainage at the back of the plain and at the foot of the rising escarpment. This line of drainage, or brook, flows down stream, cutting a gorge to the plain below and spreading there a fan-like delta deposit.

The width of the terrace plain is variable. Commonly, terraces present, toward the river, scarps which here and there show a series of concave curves meeting in pointed cusps.

It is clearly recognized that the curved terrace fronts have been sculptured by successive encroachments of a winding stream which at some time must have swung against the base of the rising scarp; and

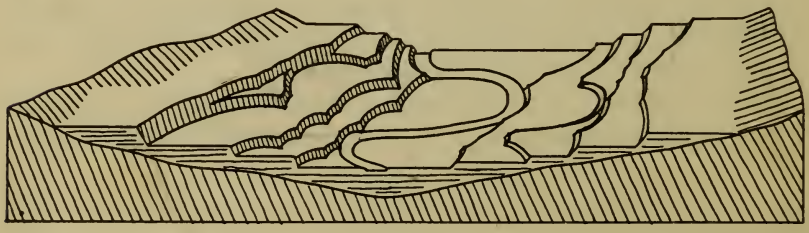


Fig. B.— Valley showing middle stage of terrace pattern. Terraces vary in width, have curved, concave scarps meeting in pointed cusps, and exist because of the discovery of defending rock ledges at lower and lower levels.

it is believed that the stream has swung laterally at least as many times as there are terraces.

Terrace scarps are steepest where the eroding stream has most recently done its work. In a series of stepping terraces, one would find the steepest slopes in the lowest and youngest, and the more gently and more deeply weathered slopes in the highest and oldest terraces. The oldest terraces not only weather to a gentler slope but, also, their edges are rounded off, which means that a convex slope of erosion is formed above and a concave slope of deposition below. Very excellent examples of this may be found by a careful study of the terraces in our valleys where the dissection of the highest and oldest terraces has been so excessive as fairly to separate them into individual plains severed by sharp and deeply incised valleys of erosion. At first sight they appear like delta sand plains with lobate margins.

Origin of river terraces in New England. — The stepping terraces of our valleys suggest a narrowing meander belt, a broad valley floor for the carving of the higher and older terraces, and a narrower valley floor upon which the rivers are to-day meandering (see profiles, plate 2). Three theories offer an explanation of this shrinkage of the meander belt. The first theory assumes a diminution of stream volume during and after the uplift which caused the rivers to degrade. It is supposed that the greater volume of the rivers necessitated a greater arc of curvature and a broader space on which to swing. To-day the streams are weakened by the loss of much of their former volume, and therefore swing with shorter arc of curvature over a more limited area, and in consequence have not the power to undercut and remove the terraces of earlier date.

The second theory postulates that the lower and lower terraces are the result of successive uplifts of the region. The river revived by each uplift cuts its channel beneath its former flood plain until grade is reached and the river swings laterally. Allow less and less time to elapse between successive uplifts, and there would be a diminution in the amount of lateral swinging as the valley was worn deeper.

The third theory (suggested by Miller, '83) points to a slow regional uplift as the cause of valley erosion and then calls attention to the rock ledges discovered by a wandering river at successively lower and lower levels producing narrower and narrower interscarp terrace plains and the observed shrinkage of the meander belt. It is this third theory which is competent to account for the occurrence and pattern of our New England terraces. The importance of this theory has been recognized and fully demonstrated by Davis ('02; '02a).

Terminology of winding rivers.— It may be well to summarize the terms used in considering the processes of river terracing. A meander belt covers the area included between tangents drawn outside of the bends or meanders of a stream. This belt widens as the meanders push outward or wear away their banks. It may also collapse locally in the case of a cut-off or short-cut. As the river moves laterally, the process is known as swinging. The meanders may be said to sweep progressively down the valley. "Up-stream" and "down-stream" refer as usual to the motion of the current, whereas "up-valley" and "down-valley" indicate a more general direction than that of the circuitous channel of the stream. The terms "right" and "left" relate to the down-stream direction of the current.

The compound movement of meanders sweeping in a swinging meander belt is called wandering. The whole breadth of the valley floor, which may be worn down by the stream, is known as the belt of wandering,— a belt which corresponds to our familiar flood plains. It is now recognized that the meanders sweep down the valley and therefore pass progressively any given point; and since at the same time the river is degrading, each successive meander must pass at a slightly lower level. The amount of difference in level is comparatively little. In the much longer time necessary for the entire river to swing across its wandering belt, the river degrades more markedly, carving a deeper scarp. Ordinarily the scarp separating terraces is a measure of the amount of down-cutting the river has accomplished in swinging across the valley and back (profiles, plate 2). The terraces left after the river has swung several times across its valley will vary in width, and they stand as remnants of the flood plains.

According to Davis ('02, p. 298), the behavior of a wandering river rests upon four postulates: "(1) The degrading stream continually maintains an essentially graded[1] condition. (2) The lateral swinging of the meandering channel is very much faster (a hundred fold, for example) than the degradation of the valley floor. (3) The breadth over which a free river (not constrained by ledges) tends to swing laterally is greater than the breadth of the meander belt (the belt included by tangents to the meandering channel). (4) An individual meander tends to enlarge its radius and to work its way down the valley until it may be abandoned at season of high water for a short-cut across a flood-plain lobe, or at any season (but usually at high water) for a cut-off through the narrowing neck of a lobe." To these postulates may be added a fifth: any departure of the thread of the current from the delicate adjustment of its symmetrical curves, caused by change of volume, cut-off, short-cut, rock barrier, accidental natural obstruction, or artificial construction, deflects the curving thread of the current throwing it into a new series of meanders.

Theory of River Terraces.

In order better to appreciate the work which the West and Connecticut Rivers are accomplishing, it may be well at this point to review the

[1] It may be pertinent to state that a river is graded, if at high water it falls in a gentle unbroken slope to the sea. A graded river may at low water reveal rapids, for a river though practically graded, is slowly degrading.

processes of river action according to the accepted theory and its deduced consequences. To this end, the lateral movement of a meandering river may be considered.

So far as these processes have been presented, they are: (1) the meander process, (2) the cut-off process, (3) the short-cut process.

Lateral swinging by meander process.— Considering the first point, — the work of a meandering stream (Davis, '03) is that of erosion upon the outer bank of its meander where the current strikes with greatest force, and of deposition upon the inner bank where the water is shallow. The current is not only swinging laterally, but is also flowing down-stream, degrading its channel to sea level. Consequently the erosion is not only at the outermost portion of the bend, but the downward motion of the water carries the current strongly against the outer and lower side. Hence the deposit is continuous and forms an even plain, sloping toward the river. Attention is called to the accompanying text-figure C, illustrating in plan the work accomplished by the meandering river, and showing that by equal erosion on one bank and deposition on the opposite bank, the entire channel of the river without changing width may move laterally across the valley, while the stream is steadily moving down the valley.

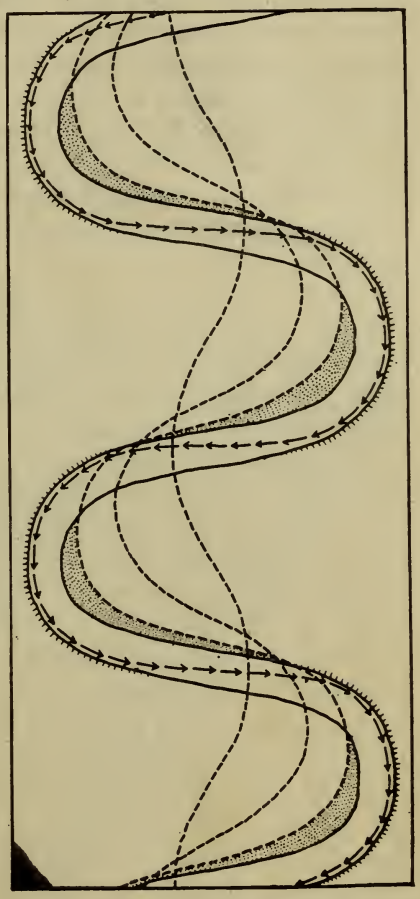


Fig. C. — River flowing forward in normal symmetrical curves. Meander belt widening by equal erosion on outer bank of the meanders and deposition on the inner bank. Erosion is strongest on outer and lower side of each meander hence the entire channel of the river moves laterally while meanders move progressively down-stream.

Lateral swinging by cut-off process.— The second, or cut-off process (Tower, '04) may be thus briefly stated: when the meanders of a river become closely compressed and widely lobate, it is possible for the stream to cut off a lobe, desert its old meander course, and follow the straighter channel to the sea. Innumerable examples of this type have been noted, and may be recognized, if recent, by a lagoon-shaped lake, silted at the ends, closing toward the river; and later by the dry and deserted crescent-shaped channel.

Lateral swinging by short-cut process.— By the third process, widely curving meanders of the river may be deserted during flood season through the formation of a new flood-made channel which gives a short-cut across the flood plain. Nothing is more evident on the low meadows which border our rivers in New England, especially in the central and northern portions where the floods are severe, than to find channels which have been rudely and quickly carved. These channels do not cut entirely across the plains, but often extend a few or several hundred feet into them. The channel banks are vertical or caving, with evidence of small land slides caused by the undercutting of a strong, rapid current, which has eaten its way under heavy pressure a certain distance, and which in another flood season may extend through the flood plain and so serve as a short-cut. Thus the river after slowly and elaborately making for itself a wide swinging meander will suddenly desert it for a steeper course to the sea. These processes of cut-off and short-cut are very common.

Lateral swinging by partition process.— There is perhaps a fourth process by means of which a river swings across its belt of wandering. This may be called the process of river partition, or the partition process. The process is of singular interest. It is by the growth of a sand bar within the stream channel that an island is formed and the river parted thereby. Eventually the deeper channel acquires the entire stream. Thus the deserted channel and the one-time island are added to the growing flood plain, and the river has moved laterally on its journey across the valley. The formation of other islands would again and again part the river, causing it to depart successively from the less prosperous channels and so continue to move laterally.

In order better to understand the formation of the sand bar, it is well to consider the meandering habit of a river. The current of any river tends to sweep down its valley in a series of systematic curves or

meanders (text-figure C) so long as there is nothing to cause a departure of the current from the normal. The radius and arc of curvature of each meander are definitely controlled by the simple law of deflection. As the meanders of the river sweep down-stream, they gradually deposit on the inner and lower side of each bend a plain sloping gently toward the river. Probably no river to-day shows a perfect type series of meanders developed by the systematic deflection of the thread of fastest current. That the river does not show this systematic arrangement is due to the departure of the current from its delicate adjust-

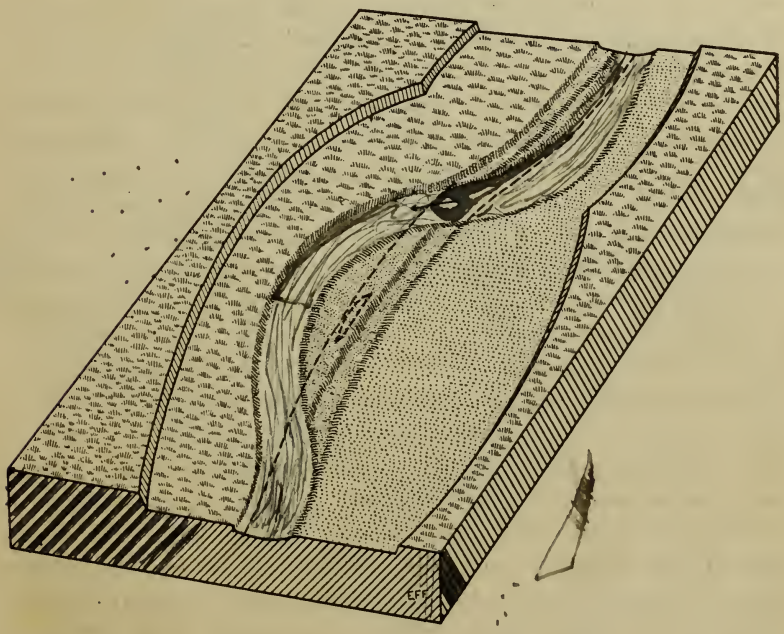


Fig. D.—Partition process of lateral movement; early stage. River adjusting its meanders to a new deflection of the current. By the growth of one sand-bar island, the river parted and has entirely departed from the weaker channel. Old channel is indicated by the dotted lines.

ment, incident upon change of volume, cut-off, short-cut, rock barrier, accidental natural obstruction, or artificial construction. Any one of these controls causes the deflection of the thread of the current, forcing the establishment of a new series of curves which cannot coincide with the former series. Any change in the direction of the strongest current

causes it to withdraw from former banks of erosion; the water there becomes shallow, and determines an area of deposition (away from the formerly eroded bank) building a sand bar which in time becomes an island. The deposition cannot be continuous with the deserted bank, as the thread of the current has been so suddenly withdrawn to the opposite side of the river. In consequence the island grows within the channel of the river near the bank from which the current has been withdrawn by its new deflection. Whenever out of adjustment, the river swings with unusual vigor, and yet is unable to re-establish itself until assisted at times of excessive flood, when the river suddenly increases its erosion and so withdraws rapidly from the existing sand bar, depositing another sand bar (text-figure G). The partition type of plain would be deposited until the new meanders were well adjusted to the new deflection. Considering the nature and the number of the causes which influence the course of streams, it is evident that a river will rarely have an opportunity to develop symmetrical, systematic meanders. But there will always be some portion of the river producing a new series of curves, and in consequence, within such portions of the river the flood plain will be forming by the partition process.

Of these controls, change of volume is probably the most influential in bringing about deflection of the stream. Any change of volume alters the radius and arc of curvature of the meanders, thus disturbing the former adjustment and initiating the establishment of another series of curves. Furthermore, many chance obstructions such as ledges, fallen trees, ice blocks, etc., encountered by the sweeping flood, throw the current into widely divergent courses. New channels are carved, and the short-cut or cut-off may be the result. The floods which at least annually sweep through the river channel are forceful agents of erosion, tearing away the unconsolidated material until the passing of the highest water, when in consequence of the decreased velocity the deposition of the transported material instantly begins in the form of sand bars. After the attainment of symmetrical curves the deposited material is regularly added to the extending meander lobes. During the development of a new series of curves, the excessive floods cause an unusual amount of erosion and a correspondingly sudden withdrawal from the filling-in bank. Moreover, the current of every stream is at least yearly thrown more or less out of adjustment by change of volume.

The short-cut and cut-off may be cited as causing the river suddenly

to desert a given channel for a distinctly different one, and so definitely to change both the position and the direction of its current. These processes are not in themselves constructive. They stop (at one place) the deposition of flood-plain layers,— let us say, of the normal type,—

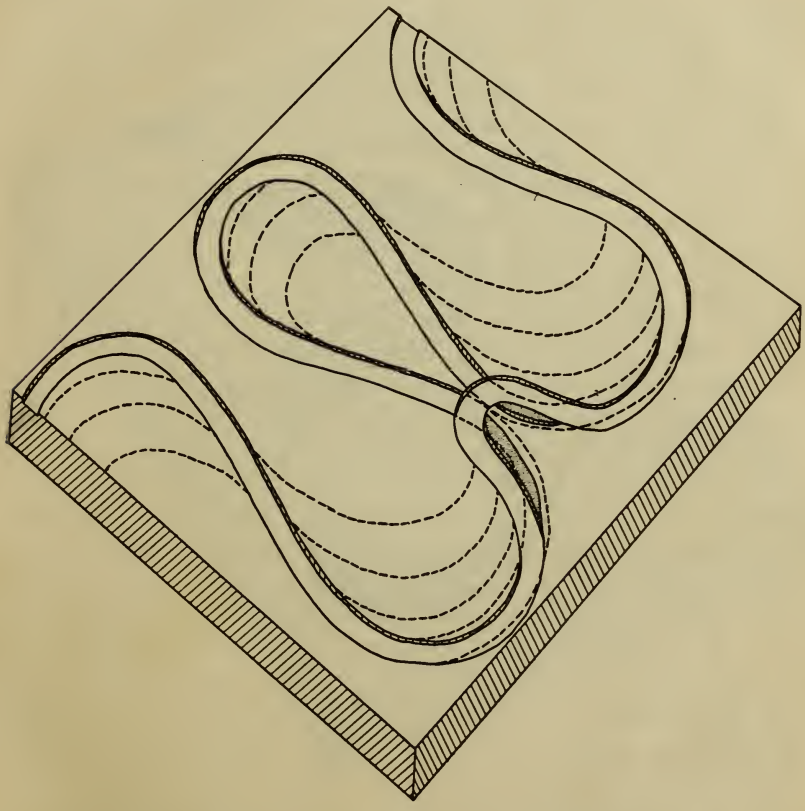


Fig. E.— Early stage of stream deflection due to cut-off process of lateral movement. The river in adjusting itself to the new bend has withdrawn from former banks of erosion by the growth of sand bars — the early stage in the partition process. The cut-off checked the formation of the flood plain by the meander-built process to allow its continuation elsewhere by the partition process.

only to start elsewhere the deposition of flood-plain layers, and this time of the partition type. A river swinging in systematic curves would regularly and continuously add layer after layer to the inner and

lower side of each meander, thus extending the normal, meander-built flood plain. The short-cut or cut-off destroys the normal curves and so causes the river to adjust itself to a new series as clearly demonstrated by Tower ('04). The new channel instantly deflects the thread of the current, and causes the formation of sand bars just

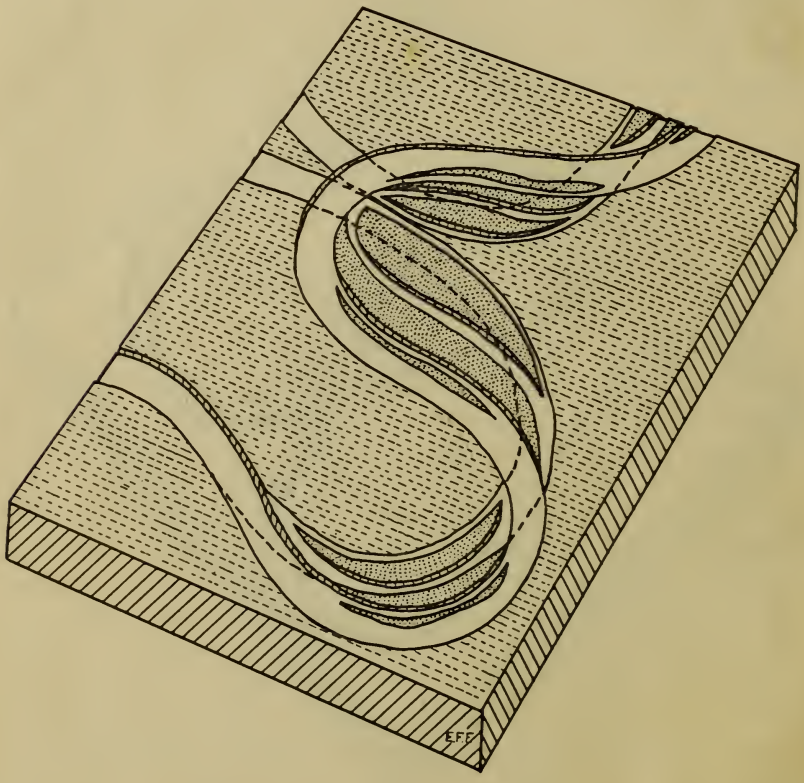


FIG. F.— Stream deflection due to cut-off. Later stage of E in adjustment of the river to the new meanders by the partition process. River has been successively parted by three sand-bar islands.

above and below the short-cut or cut-off. The accompanying figure illustrates the change in the work of the current, initiated by cut-off.

Tower ('04, p. 593), in describing the shallow water deposits resulting from a cut-off, speaks of these deposits as "fills," and says: "Fills may or may not be continuous with the former banks; for the sudden

change of the current may on the first fill down valley from the neck cause a deposition away from the bank and separated from it by a narrow strip of water or slough." Tower also cites a recent cut-off at Cole's Point on the Mississippi where the down-stream fill from the cut-off appears "as a distinct island, with a slough behind it, indicating a rapid change in the position of the current."

A rock barrier likewise deflects the thread of the current causing a readjustment of meanders. The sign of the readjustment, *viz.*, the partition process, is always more noticeable above and below the obstruction and grows less and less prominent up and down stream. If a rock barrier is encountered near the apex of a meander, the river by withdrawing slightly to the center of its valley may succeed in slipping past. The withdrawing and the slipping past indicate a necessary deflection of the thread of the current. Consequently the river impinges below the ledge and must withdraw from the channel cut above. Sand-bar islands appear when the withdrawal is sudden, and the river forms a new series of curves. Should a rock ledge be discovered below the apex of a meander, the river is unable to slip past, and is strongly compressed above the ledge. Again the normal sweep of the meander is prevented, therefore the river above and below the compressed curve must conform to the new deflection. Sand bars and partition plains are the result.

Any accidental natural obstruction, which temporarily fills a portion of the channel, such as a fallen tree, a slipping down of the sod, a piling up of logs, an accumulation of surface debris, etc., effectually deflects the current and initiates a new adjustment of meanders.

The effect of any such artificial obstruction as a pier, dam, or bridge is to prevent the river from continuing its normal swinging. The river must therefore spend its energy in cutting new meanders and filling the deserted portions of its course with deposits and possibly sand bars. The new curves established as the result of a bridge differ from curves formed by a cut-off deflection, since a bending must occur above and below the bridge, while by cut-off a new meander develops, growing outward and down-stream from the cut-off meander.

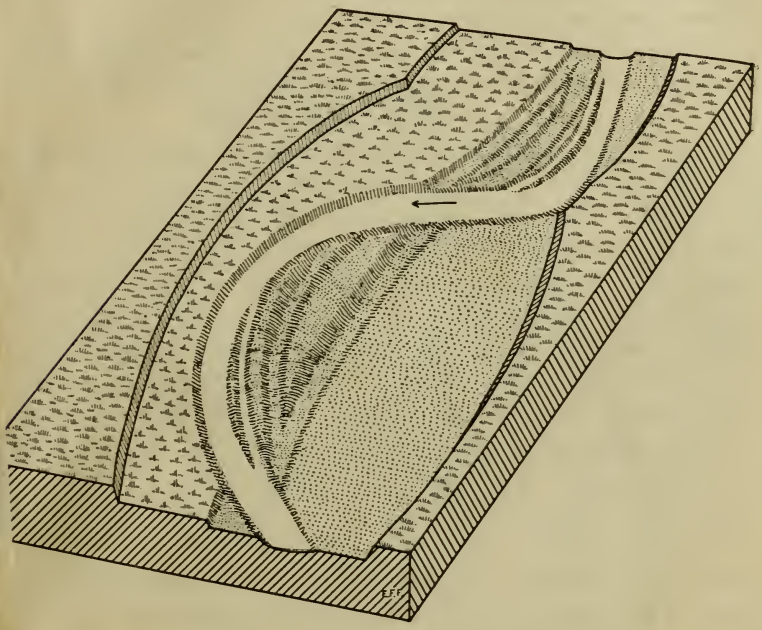
A clear example of the partition process exists about seven miles from Brattleboro where the Putney road crosses a young meandering brook known as Canoe Brook just south of Canoe Brook farm (see photographic illustrations, plate 11). The current has withdrawn by successive deflections from a rather well developed series of right- and

left-hand meanders to a winding but much straighter course and each deflection has been so rapid as to leave a series of four distinct islands of less and less curvature from the former meanders to the present almost straight course (as illustrated by the photograph, pl. 11, fig. 1). These resultant, undulating plains will be described under the development of partition plains. Other series of equally good sand-bar islands and one-time channels appear along the brook. These deflections have resulted from a large quantity of fallen tree trunks and brush, that initiated a left-hand deflection about a hundred feet up-stream from the road. At flood season short-cuts have been carved as a result of the new adjustment. At the lower end of the photographed meander, special sand-bar forms were constructed resulting from the discovery of a barrier of clay made firm by the roots of trees. This barrier chanced to be below the apex of a left-hand meander. The meander became more and more compressed causing the brook to bend up-stream to encircle the barrier, and that deflection enforced a withdrawal from the compressed bend and the formation of sand bar after sand bar until the brook flowed comfortably by the barrier. The entire brook for several hundred feet has successively withdrawn more and more from its meanders by a combination of the partition and short-cut processes.

Development of the partition plain.— A deflection of the current by any of the afore-named processes causes rapid erosion and the consequent widening of the channel. The river in struggling to withdraw rapidly from the opposite bank deposits on that side, and yet away from it, a sand bar which soon develops into an island. Continued outward cutting by the thread of the current causes the river to withdraw more and more from its shallow bank (see text-figure D). The downward cutting of the thread of the current deepens the wider and stronger channel, thus drawing the water off from the more shallow channel. Erosion continues gradually until flood season, when suddenly more erosion takes place and much material is deposited, forming sand bars which part the river. As the current departs from its weaker channel, this abandoned course and the one-time island are added to the growing partition plain; and the river has moved laterally an appreciable amount.

The continued deflection of the current allows, at times of excessive flood, the formation of another and yet another sand-bar island, which upon the departure of the river from the weaker channels are succes-

ively added to the growing, undulating plain. The growth of such lains is more rapid immediately following the change in the deflec- on of the thread of the current, and slowly decreases as the river pproaches the series of normal curves.. Since the rivers, though



IG. G.— Partition process of lateral movement; later stage of Fig.D, showing three islands which have successively parted the river. At times of successive erosion the deposition has been withdrawn from the former bank, causing the growth of the sand bars.

d, are constantly degrading, the deserted channels and the ls are successively lower and lower, and the flood plains though ating, slope slightly toward the river.

h sand bars may be formed in any meandering river whether ling, graded, or aggrading. By degrading, the more active ıs drain the water from the growing partition plain, and by the ued deepening of the main channel the successive sand bars posed. They are narrow and show rather strong parallelism ıe old and new river banks. The sand bars of the less active, nature rivers accumulate slowly and form much more perma- ılands. They are large in extent, often forest-covered and

receive additions where the current is not strong, usually along the filling channel and at the up-stream end. Observations upon our essentially graded New England rivers show the prevalence of these sand-bar islands. The West River as it flows into the Connecticut shows three islands of varying sizes and the younger, less mature streams that descend from the valley sides into the West and Connecticut Rivers exhibit many such islands. The island though usually of systematic sand-bar formation may be accidentally the result of short-cut. Islands of this type will be considered later.

The West River is to-day parted by a sand-bar island at the 205-foot level (see plate 1). This island is the first of a series by means of which the current of the river is adjusting itself to a comparatively recent deflection caused by short-cut from the base of the Retreat Meadow. The thread of the current and consequently the deeper channel are on the right. At low water the left-hand channel is dry, and the pebbly, gravelly material covering its floor, grades gradually to the level of the island. During the subsiding floods, the up-stream current, entering the shallower channel, is more or less checked, and therefore deposits, gradually building up the floor of the soon-to-be-deserted channel. With continued wash-filling, the old channel will be recognized not by a perfect river bed but by a valley-like depression.

Two other islands occur in the West River before it reaches the Connecticut, and the Connecticut is parted by a large island at Brattleboro. The current of the Connecticut flows through the wider right-hand channel. At low water, the left-hand channel is almost deserted, and inevitably it will be abandoned in the future. The river will then have moved materially to the right. Its further progress in this direction cannot be great because of the artificial constructions. Innumerable other instances of partition and the resulting lateral movement of the Connecticut might be cited. The process, however, may be studied more simply if reference be made to the younger, more energetic side streams. Just before Canoe Brook seven miles north of Brattleboro, reaches the main stream, an island, unquestionably of sand-bar formation, appears in the middle of its course and the water divides to flow around it (plate 10). The thread of the current, deflected to the right, has cut down so vigorously as to produce a fall of water. Continued erosion of the stream will cause the fall to move headwards, and the two streams will exist until the waterfall has retreated far enough to acquire the more shallow

stream causing it to depart from its channel, — a change which is inevitable because of the lower grade attained by the more vigorous stream. As a result, the left-hand channel will be deserted, a sand bar added to the left-hand widening flood plain, and the river moved

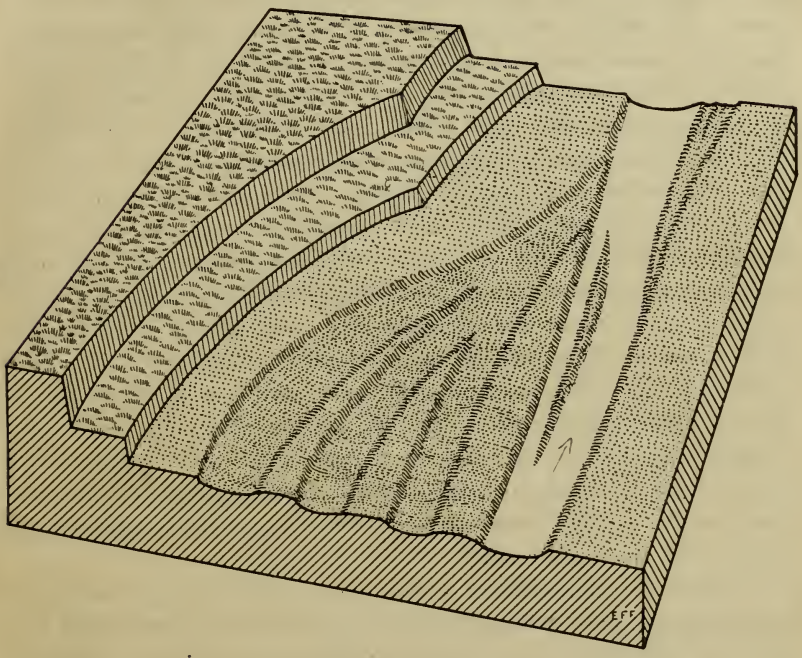


Fig. H.— Diagram of the mature stage of the partition flood plain built by Canoe Brook seven miles from Brattleboro, Vt. Ridges represent the one-time sand-bar islands and the valleys the deserted river channels. Current flows toward top of figure.

to the right; and thus one stage of the process will be complete. So long as the new curves are being developed, the position of the river channel, noticeably at flood time, may be greatly changed, and there will be a repetition of the island process. A few hundred feet up the brook just referred to, there is a good illustration of the same process in a more mature development (plate 11 and text-figure H). To the left of the stream, four deserted river channels are found separated

by ridges, former sand bars. And so recent are these changes that the entire process is clearly demonstrated. The material of the sand bars and channels is coarse gravel. The deserted river channels are not well defined with flat bottoms and steep sides, but the plain is undulating. The entire surface is swept at flood, and further deposits may tend to obliterate these irregularities. The undulations are no greater than appear upon many of our broad flood-plain areas. At Hadley, the Connecticut at its great right-hand meander has left a series of islands on the up-stream side of the down-stream portion of the bend, which give to the plain an undulating surface, as pointed out by Emerson ('98). In describing the Sunderland, Hatfield, Hadley, and Northampton meadows, Emerson says: "The plain that seems so perfectly level when seen from above, proves on closer inspection to be made up of a series of broad, low ridges, like the long, low swell that comes in on the coast after a distant storm, and the curved grooves which separate these ridges run approximately parallel to the bank of the stream but with greater or less curve. This is due to the composite nature of the terrace itself ..... Each of these low bars represents one of the elements out of which the terrace is built and has passed through the stages of bar, island, and 'glacis terrace'[1] as it has added itself to the previously formed plain, while the groove on the outside of each ridge, (out from the river) is the unfilled remnant of the waterway which separated the island from the former shore.

"The surface of the broad terrace plain north of North Hadley and extending up to Sunderland shows this most strikingly, and when seen from the hill just north of Hatfield, each separate island of which the terrace was built by the westward swing of the river can be picked out."

With reference to the topography of the meadow at Brattleboro,— the area is wide in extent, and from a distance appears like a level plain. A careful survey, however, shows elevations and depressions, comparatively distinct to-day, notwithstanding the fact that the entire surface has been ploughed and re-ploughed for agricultural purposes. At the base of the Retreat scarp is the brook drainage characteristic of many such flood plains. A closer examination of the high and low areas reveals the existence of a series of valleys, representing channels

[1] Hitchcock, "Surface geology," 1860, p. 5.

from which the parted river departed on its passage to the right across the meadow. A natural conclusion would be that the West River, having reached the Retreat scarp by the partition process, was withdrawn by a short-cut to its present position, from which it is again moving to the right by the island process.

At flood season the entire meadow is covered with water. As the water subsides, the old channels left by the partition process are occupied by the lingering water, and thus mark with some clearness the positions which the stream may have held as it gradually moved to the right. Some of the higher levels observed along the banks of the West River must have been produced by flooding. The floods are strongly marked within this area. Not uncommonly it happens that trees are uprooted or lose their bark. The water descends with great suddenness, transporting huge blocks of ice for long distances and often twenty feet or more above the present meadow level. As the water subsides, such a flood would deposit much material, therefore increasing the height of the river banks, and adding to the sand bars.

It is quite possible that the swinging of a river from one side of its meander belt to the other may be accomplished by a combination of short-cut and partition processes. A series of short-cuts produced at flood causes the stream at low water to follow in part its old channel and in part its new short-cut channel. Such a flood-plain island determines the parting of the river and is a measure of its lateral movement. The flood plain exposed on the left-hand side of the West River is deeply eroded and cut into at flood season. Should any one of these cuts be carved entirely across that flood plain, incision might be below the level of the West River channel and so cause a further parting of the river around a short-cut island. The largest island in the West River, because of its structure, size, and forest vegetation, may be a portion of the flood plain separated by a left-hand short-cut.

The partition plain may be defined as young, mature, or old. The young plain is characterized by clearly defined ridges and channels of sand-bar material slightly elevated above the water level. So recently abandoned are these plains that they show no signs of erosion, are rarely grass-covered,— indeed, the probability is that they are still swept by floods, receiving additional flood-plain deposits. The mature plain is more gently undulating, because the floods have so frequently swept over it as to fill in the valleys with fine silt and possibly to remove the crests of the ridges. The mature plain is dry, not covered by water,

and often the river has swung broadly away from it. The old plain is more wavy than undulating. The sand bars and the intervening channels are no longer distinct. It is difficult and practically impossible to define the positions of the courses from which the river successively departed. It is probable that the plain will be elevated above the river which, since the formation of this plain, has degraded to lower and lower levels, forming younger and lower plains. Such elevated old partition plains will show signs of weathering and dissection.

As a result of these processes, two types of terrace plains are constructed, the meander built and the partition built. The first type is formed by the regular deposition at the inner and lower side of the down-stream sweeping meanders. Such a terrace is even and nearly level, sloping gently toward the meander, and is the type generally recognized as the normal flood plain. A second constructive type is produced by the partition process. A terrace so formed slopes gently toward the river, but is undulating, with elevations and channel-like depressions, representing the former islands and the intervening deserted channels. The other processes of lateral movement check deposition in one place to start it elsewhere. They straighten the river locally, and by destroying the existing curves, deflect the current, forcing it to establish a new systematic series of meanders. The new deflection of the thread of the current withdraws the stream from former erosion banks by the deposition of a series of sand-bar islands, leaving partition plains.

Terraces of the West River Valley.

Terrace pattern, early stage.— Terraced valleys show different stages of development: the early stage, the middle stage, and the late stage, corresponding to the stages of youth, maturity, and old age. In the early stage, the river valley has commonly but one or two terraces, perhaps one completed terrace and one low flood plain. They show clear cut, simple forms, few in number, wide in extent. The terrace pattern is without the complexities of middle life and has the most immature development of terrace drainage, if any. Any terracing brook furnishes a good example of this early stage, showing forms

which have suffered no weathering and only slight undercutting by the swinging of the brook. This simple ideal type, represented in text-figure I, shows at least one distinct terrace, with scarp concave toward the brook, and more or less cuspate,— the cusps formed between the concave incision of the meanders of the brook. As each meander sweeps down the brook valley, it probably diverges sufficiently from its original angle of incision to make a series of these concave cuts, uniting in noticeable cusps. These cuspate edges are most apparent when the terrace scarp faces the brook, and are entirely wanting when the terrace scarp has been carved by the forward extension of an arm of the meander. The text-figure I shows that such sweeps of the terrace scarp face up-stream. An illustration may be seen on plate 1. The low terrace facing the right side of the meadow is distinctly cuspate just before it makes the long, concave curve of the Retreat scarp. A meander of the West River carved the deeply compressed Retreat scarp after it had successively cut the right-hand cusps.

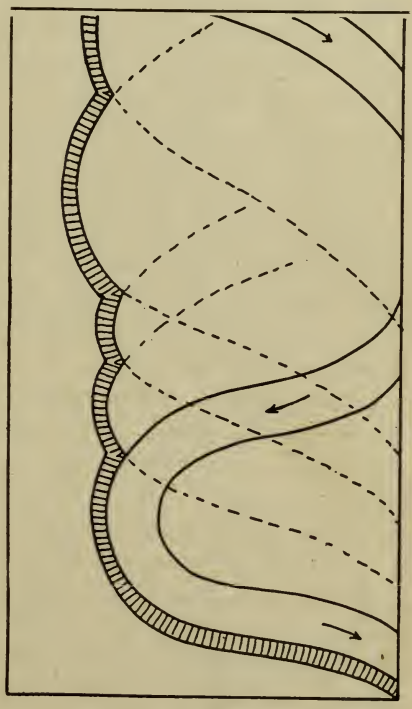


Fig. I.— Ideal terrace pattern; early stage. As each meander progresses down-valley, it vacillates sufficiently to carve the curves and cusps characteristic of the early stage of terrace scarps.

Three of the early stages in the development of the West River terraces may be traced as shown by diagrams (pl. 3, figs. 1, 2; pl. 4, fig. 3), which are necessarily more or less hypothetical, since it is impossible to-day to locate with absolute definiteness the positions occupied by the river thousands of years ago. The West River has been swinging and slowly degrading its aggraded valley since the glacial period. In following its left-hand wanderings, there are rem-

nants of seven terrace levels marking at least as many and probably more left-hand swings. The earliest record is given by the highest 347-foot level (pl. 3, fig. 1). That plain, now limited in extent, skirts the left-hand rock hill — the limit of swinging. The once more extensive plain was nearly consumed by the river as it swung to the left later at the 304-foot level (pl. 3, fig. 2) carving a scarp in the higher 347-foot terrace. That scarp, the oldest to the left of the river, is now weathered with rounded edges and deeply incised transverse valleys, but thousands of years ago when the river flowed at its base, and the entire valley was filled to the 304-foot level, that high terrace scarp was young, with a sharply defined straight edge. A third time as the river swung to the left it eroded the 304-foot plain leaving a scarp descending to the 291-foot flood plain (pl. 4, fig. 3). This third position of the river is the most hypothetical, and is based only upon the two limited scarps at the back of the triangular 291-foot plains (plate 1). The remnants of these early plains are assuming old forms. They distinctly represent the highest plains in the valley, and those that were first formed.

Terrace pattern, middle stage.— Allow the river to continue its sweeping and swinging, and a terrace pattern of some complication may result. It is possible that the river may cross and recross its valley many times. On the northeastern side of the river (plate 1) are shown the results of at least eight swings including the present position of the West River; and this is probably not a full count.

Having carved the three highest terraces, the river continued to degrade and to swing back and forth across its valley, carving and depositing four terraces at successively lower and lower levels as accidentally determined by rock barriers, short-cuts, or cut-offs. The complexity of terrace pattern of the middle stage is determined by the remnants of the three early and four later flood plains as represented in diagrams (pls. 3, 4, 5, 6). At a later return of the river to this side of the valley (pl. 4, fig. 4) it was flowing from 279 to 280 feet above the sea, and succeeded in almost completely removing the remnants of the 291-foot flood plain. The two small triangular areas shown on the fourth diagram (pl. 4, fig. 4) represent all that remains of the formerly more extended 291-foot flood plain. So perfect are these triangular areas to-day that they seem almost like models. When the river returned for the fifth time to the northern side of its valley, it was flowing at the 262- or 263-foot level, and the scarp cut was 18

feet. The river must have been meandering in great loops, extending one meander far into the 280-foot terrace, then curving broadly to the other side of the meander belt and returning so as to make a more extensive cut into the same flood plain. The evidence of this is most clear. A rock barrier held the first meander mentioned, at its lower side, and prevented the cutting away of the long spur of the 280-foot flood plain. This necessarily deflected the river broadly to the western side, and returning, it cut the extensive bend, represented to-day by a distinct ox-bow channel, a course from which the river was withdrawn by a short-cut. It is interesting to note that the outer bank of this great meander bend is distinctly cuspate, which would seem to indicate that the current impinged with varying force upon the bank of erosion. On the sixth return (pl. 5, fig. 6), the river apparently cut to the 225-foot level, which produced a scarp of 38 feet. This scarp is distinctly deeper than the other one-swing scarps of the valley. Presumably the same amount of time was necessary for the river to swing across its valley; therefore if the power for degrading remained the same, this scarp is not a one-swing but more probably a two- or a three-swing scarp. Evidence from the other side of the valley may tend to prove in the absence of intervening levels, whether this is a one- or more-swing scarp. The small terrace which appears at the northwestern end of this 225-foot level is so insignificant — only one or two feet above the 225-foot plain — that it is more probably a two-sweep terrace and does not indicate a swing of the river. On the seventh return (pl. 6, fig. 7) the river flowed at the back of the 209- to 214-foot level. Evidently as the river moved from this position, it swung strongly to the right, reaching the base of the Retreat scarp,— chiefly by the partition process. By short-cut, across the narrowing flood plain, the river was withdrawn to its present position on the left side, and is flowing now at the 200-foot level. This last short-cut disturbed the adjustment of the current, deflecting it to the right and causing the formation of the large island at the 205-foot level.

The form and position of the 291-foot cusps (pl. 4, fig. 4) are accidental, carved by the intersection of two lines having no particular relation to each other. All the elements of these cusps are variable, influenced in some other way than by a common control. They may be considered typical cusps formed by an unguided, swinging river. A definite arrangement and grouping of cusps is recognizable

at the two extremities of the 225-foot plain, where the rock outcrops produce a series of stepping terraces. No such definite arrangement of cusps, one back of another, could exist by accident. A better example is found (plate 1) west of the meadow, in the vicinity of the farm buildings, where the curving terraces terminate and are replaced by the rock ledges which—as will be later explained—form the control for the systematic arrangement.

Terraces of such complications frequently show a perfectly developed system of terrace drainage. This system exists upon the Retreat plain and the meadow plain. A line of drainage follows the back of the Retreat plain to its lower end. There the brook has eroded for itself a valley to the meadow plain and deposited on the floor below a fan-like delta. The Retreat plain slopes to this line of drainage, indicating that the plain was built while the river occupied the position of the present brook and that the river was finally withdrawn by short-cut or partition. At the foot of the Retreat scarp on the meadow is another brook, following what may have been the old course of the West River and now emptying into the present river.

Such complexity of terrace pattern as exists within the West River valley is typical of the middle stage, because rock ledges were discovered to defend and preserve positions of the many terrace plains. Moreover, the remnants of the higher terrace plains are few and small, since they have been repeatedly undercut and destroyed; and the lower plains are larger, more numerous, and better preserved because time enough has not elapsed for them to be frequently attacked by the river.

Terrace pattern, late stage.— When the power of a river to degrade weakens, it devotes its energy to swinging repeatedly to and fro across its valley. In the absence of rock ledges, even the basal terraces disappear, and the intermediate plains may be completely swept away. The river thus swings until it reaches the limit of its wandering belt; and the whole descent from the high-level terrace to the existing flood plain is made in one deep escarpment.

Three conditions may bring about this weakened ability to degrade, as Davis ('02) has shown: first, the attainment of nearly fixed values of volume and load, such as might be reached when a glacial climate had given way to a milder climate and the latter had become well established; second, the cessation of any slow uplift by which degradation had been initiated or aided; third, superposition of the stream

on a strong rock sill on which corrosion is very slow. Any one or two of these conditions may have weakened the ability of our New England rivers to degrade. And they are essentially graded for long stretches and therefore devote their energy to swinging. The river-terrace topography such as is found along the Connecticut in the vicinity of Holyoke and Springfield suggests that possibly here the river has been prevented from degrading lower, and (in the absence of more controlling rock ledges) has left high, strong escarpments on either side with a few low terraces in the more central portion of the valley.

Were there no controlling elements, it would be surprising to find

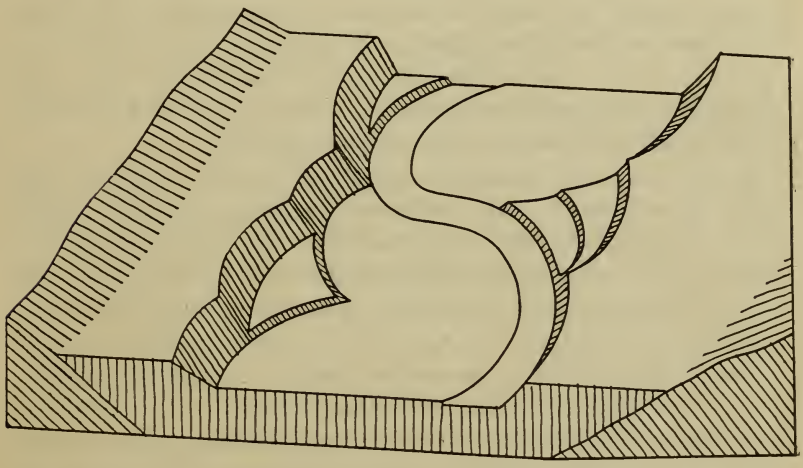


Fig. J.— Ideal terrace pattern; late stage. Absence of rock ledges has made it possible for river to wander broadly, removing the intermediate terraces. Descent from the highest terrace to the flood plain is concentrated in a single high scarp. Central portion of valley shows a few low basal terraces.

preserved a series of eight stages in any such valley as that of the West River at Brattleboro. Evidently the factor which has made possible the preservation of the remnants of these terraces must be due to another and eminently important cause, *viz.*, the rock ledges.

Influence of rock barriers upon the form and preservation of the West River terraces.— It has been stated that a free-swinging river in an aggraded valley will by degrading discover the rock prominences or reefs of its floor; and the outcrops of ledges so discovered will be constantly at lower levels and nearer the center of the valley. These

ledges defend and protect the higher terraces. Only a small portion of the flood plains, however, is left back of such defended cusps. There may extend down-stream a long trail of the same flood plain to mark its more widespread extent; and the trail only exists there because of the up-stream and possible down-stream cusp which has prevented the river from swinging more widely and so consuming the entire terrace. The extent of such terraces from the point of protection will vary from a few feet to several hundred. If the ledge discovered lies near the apex of a down-sweeping meander, the meander may succeed in slipping past it by withdrawing slightly toward the center of its valley. The obstacle is thus avoided, and the river impinges deeply on the down-valley side. An example of this type is seen where the West River slips by the rock on its right bank at the pumping station, and is now sweeping broadly to the right. By slipping past this and other rock barriers the river succeeded formerly in making the entire sweep of the meadow (plate 1).

To the west of the meadow and south of the farm buildings there is a strong rock control. At three succeeding stages, when the meander reached this point, the rock ledge was discovered below the apex of the meander. In such a position the meander could not slip by, but was forced to bend outward and cut a curved re-entrant in the terrace front next up-stream from the ledge. The meanders farther up-stream continued their advance down-stream, which compressed the meander next to the ledge to a relatively strong curvature. This sharpened the defended cusp and caused it to point up-stream. The features which represent this control are the rock ledges to the south, the sharp bend or the deep concavity of the terraces to the north of the defining ledge, and the sharp cusp of the ledge pointing up-stream. The area of the West River just described is of special interest since it shows that the form and outline of the terrace front have there at least been wholly controlled by the definite rock ledges and the accidental position which they held with reference to the meanders of the river. Three times it happened that the defining ledge was on the tangent between two meanders or at the point of river inflection; and the last time as the river was sweeping around the meadow, the defining ledge chanced to be near the apex of the meander. In the first instance the stream could not slip past, whereas at another time, slipping past, it did its greatest work below the defining ledge. Examples of rock control on the left side of the valley have been cited. It frequently

happens that ledges which have been of greatest importance in controlling the deflection of streams are not visible because of wash deposits which could most easily cover and apparently obscure them. Yet the terrace patterns which appear, make it absolutely evident that a ledge existed there. Otherwise the left-hand, 280-foot alluvial spur would have been swept away by any river swinging strongly against its northern up-stream side. The positions of the rock ledges on the map give many other illustrations of rock control, though possibly not so striking as these. For instance, as the West River swung to the left at the back of the 220-foot level, its meanders impinged against the alluvial material and would probably have eroded more to the left had it not been for the existence of the rock ledges. As the West River swung southward across the meadow, its passage to the right was definitely limited by rock ledges.

Diminished swinging of the meander belt.— While rivers are flowing at high levels in their drift valleys, they may not be expected to encounter ledges. As they cut deeper, the possibility of encountering rock grows greater, and rock ledges are constantly nearer and nearer the axis of the valley and so tend to narrow the meander belt. As the valley deepens, the number of defended cusps tends to increase; and as the meandering belt is narrowing because of the rock barriers, the horizontal distance between low-lying scarps must be less than between the high-level scarps,— a principle which is of great interest in this connection because it shows that the narrowing of the valley must be a normal result due to the discovery of rock ledges and not referable to diminution in volume as according to the earlier but discarded theories.

Since there is no normal distribution of reefs of rock upon the valley floor, their discovery is not only accidental but without systematic arrangement. Consequently the rock reefs which appear on both sides may chance to be near the axis, and so narrow the valley, or may be widely separated, and so enable the meander belt to cover a broad area. There may be stretches along any river comparatively free from ledges, or if not free, in which the ledges lie so low as to have little influence and to allow a broadly open valley. Under such circumstances, few of the middle terraces will be preserved, and on either side will be a high, strong escarpment with a few low-lying escarpments protected by ledges. The Holyoke-Springfield district may again be mentioned as an example of this type. Such types, however, attract comparatively slight attention, since it is the existence of step-

ping terraces, and not the absence of them, which arouses interest. The Whetstone Brook at its junction with the Connecticut River at Brattleboro, is a vigorous, active stream, swinging within a comparatively narrow, rock-bound valley. In its swinging and degrading, the brook has uncovered ledges at each lower level, thus successively narrowing the width of its wandering belt. Consequently a most excellent example of stepping terraces occurs, being of sufficient width to allow the construction of a street and its houses with cross-roads ascending the terrace scarps. This topography is recognized as a unique feature of the town.

The distribution of high and low scarp terraces as typically developed

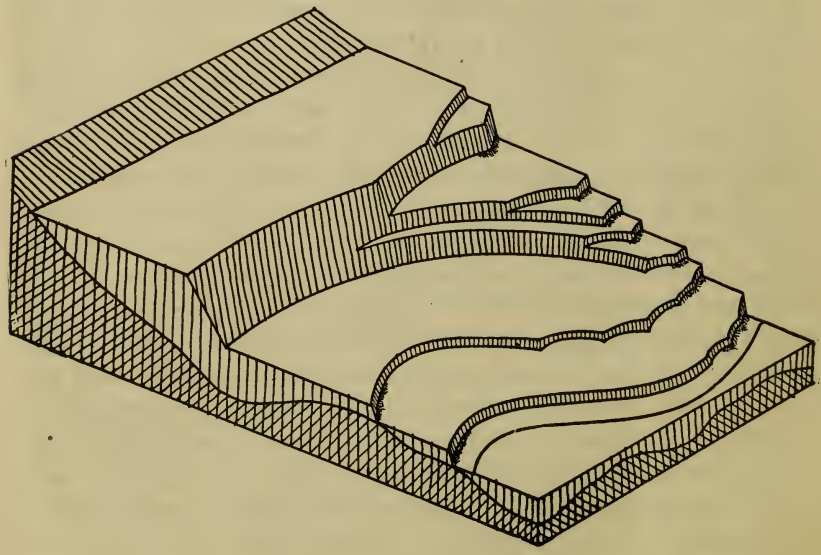


Fig. K.— Distribution of high-scarp and low-scarp terraces as controlled and defended by rock ledges.

is illustrated by text-figure K. Assume that a low-scarp terrace is first formed along one border of the belt of wandering. After a few swings, a ledge is discovered, consequently all the terraces of earlier swings lying back of this ledge are preserved. Every later swing of the river is checked nearer and nearer the axis of the valley, because of the sloping surface of the buried rock ridge. A flight of stepping terraces is formed as a result of the defended cusps. Down-stream

from the defended cusps, successive terraces may be consumed, until by chance a lower rock ledge may be discovered. Such a lower ledge would protect the last flood plain and the high escarpment back of it. Davis ('02, p. 320) has concluded "that low undefended, high-level terraces of early swings are most likely to be preserved back of defended cusps of later swings; that the undefended terraces of early swings would probably be swept away in the production of a single high scarp terrace wherever broad swinging at low levels is not prevented; and that when high scarps occur in a flight of stepping terraces they are more likely to be found at or near the top than at the bottom of the flight."

It is therefore evident that the preservation of the many flights of stepping terraces has been made possible by rock ledges — an eminently important control — as was suggested by Miller, as Davis has clearly demonstrated and as is proclaimed by almost every river terrace in New England.

Relation of terrace pattern on two sides of valley.— It is a generally accepted fact that the terraces on the two sides of the valley of an essentially graded river slowly degrading, do not necessarily agree in number or in height. The complete swing to and fro across the valley results in an appreciable amount of degradation. In the Brattleboro region, twelve feet appears to be a characteristic one-swing scarp. The difference need not necessarily be always maintained, since by the cutting-off process the river is immediately withdrawn to a new position. Much evidence has been given to prove that the number of terraces remaining on opposite sides must be accidental as determined by constraining ledges, so that the same number or a widely differing number may exist on the two sides,— assuming always that they were systematically formed on both sides, but that one or more may have been completely removed. Another fact with reference to the terrace plains is that they slope with the stream; if the grade of the river is a strong slope, the difference in the up-stream and the down-stream ends of the plain will be appreciable. The West River (see profiles, plate 2) at Brattleboro shows a fall of ten or twelve feet in a distance of a half mile, consequently the meadow shows a grade of probably ten or twelve feet within the same distance. Such a down-stream slope of the flood plain makes it difficult to correlate the terraces on opposite sides of a steeply graded river, because any change of grade would have directly affected the slope of the flood plain. Granted

that there has been no change in grade, the distance and the fall per mile must be calculated so as to correlate the order of deposit of the flood plains on the two sides.

The profile map (plate 2) gives two actual cross sections, one from east to west along the line A-B, and the other from northeast to southwest along the line C-D. The scale of profile does not admit the showing of the more delicate slopes and undulations of the plains. The cross sections emphasize any possible relations existing between the plains on either side of the river. These, in connection with the ideal profile, show a difference in the number and levels of plains on the two sides. The higher scarps are the sum of two or three scarps of lower plains which were consumed by the river as it swung more widely than on previous swings across its valley. Perhaps the greatest value of the profiles lies in the fact that they indicate that while the river is swinging laterally it is also always steadily approaching sea level. Could we stand for untold ages and observe the river, we would see meander after meander progressively passing gradually by, and we would also see the entire river channel move or swing back and forth within its narrowing meander belt.

History of the West River Valley.

This West River branch of the Connecticut rises among the hard crystalline Green Mountain hills of southern Vermont, and flows southward and eastward across the metamorphic rocks to the Connecticut. A valley narrowing up-stream had been carved preglacially in these rocks. During and at the close of the glacial period, the valley became aggraded with more or less wash drift to the elevation of the highest plains which now rest against the rock boundaries of the valley. The river has since then by wandering and degradation carved the present valley topography, wandering at first freely in the unconsolidated material until at lower levels the rock reefs were encountered and served as a defence for the remnants of higher flood plains. The highest plain within the valley, *viz.*, the Golf Links area, is not of simple origin. Its surface is rolling, consisting of morainic and kame-like material. The upper layers are of coarse gravel, then sand, and below, clay,— a clay outcropping at an elevation of 375 feet. These deposits may have been continuous across the valley at the

early stage when the river began its degrading work. The general appearance and character of the deposit would suggest that the high area is one of local out-wash from the higher ground during the period of aggradation. The area may be considered as a delta surface, built up in standing water, perhaps the flooded West River. As we descend from this delta plain and its lobate slopes, we pass successively younger and younger terrace patterns. The older and higher ones show deeply incised valleys, rounded edges, and long wasting slopes of erosion. At the bottom of the series, in contrast, we have sharp terrace edges and steep terrace scarps with few or no evidences of erosion.

The terrace patterns of the West River are ideal young and middle-stage patterns, showing free and defended cusps. The strong defending rock ledges south of the Retreat farm buildings, at the pumping station, and the strong rock barrier east of the meadow are good illustrations of the influence of such accidental barriers. The wandering belt of the river has been constantly narrowing by reason of the discovery in its swinging of rock barriers nearer and nearer the axis of the valley. The flood plains of the West River valley are both meander-built and partition-built. The 262-foot plain on the left side of the river is a typical meander-built plain, and the meadow is a good example of a partition plain.

It is evident that in the future the river, if undisturbed, will abandon the left-hand course about its large sand-bar island for the deeper right-hand course. It will thus swing to the right unless another deflection causes a change in the direction of the current. At present flood-carved gullies cut deeply into that left-hand flood plain, and their further extension through the plain will produce a short-cut thereby preventing the right-hand incision of the meander and thus straightening the course of the river.

Conclusion.

Obviously the conclusion to be deduced from the foregoing study is the one already suggested,— that Miller's theory of defending ledges affords a better explanation than any other for the terraces of our New England valleys. These terraces are not in every instance defended, though all the flights of terraces exist in consequence of defending ledges. A lessening of the river volume and interrupted uplifts appar-

ently have not had great effect in confining the swinging and slowly degrading river to more and more restricted belts. The narrowing of the valleys results rather from the confining influence of rock ledges discovered successively nearer and nearer the center of the valley. Another conclusion, moreover, is that the curves and scarps of river terraces may be most minutely accounted for, and that the action of a meandering and swinging river fully explains every detail of terrace forms. The West River terraces not only confirm the theory but also the entire train of consequences as deduced by Davis.

Further, and a far more important conclusion from this study of a meandering and swinging river, is a better knowledge of the controls which determine the behavior of such a river. A river of definite volume swinging freely in unconsolidated material tends to flow forward in symmetrical curves. During the approach and after the attainment of the symmetrical curves of this normal type, continuous deposits are formed on the inner and the lower side of each down-stream-sweeping meander causing the growth of an even plain sloping slightly toward the river — the meander-built plain. Such a perfect series of river curves is rarely if ever developed because of the many accidents which by new deflection cause a departure of the current from the normal delicate adjustment of its symmetrical curves. Such a departure of the current may be caused by change of volume, cut-off, short-cut, rock barrier, accidental natural obstruction, or artificial construction. Any one of these controls may so throw the river out of adjustment as to initiate the formation of a new series of meanders. The sudden deflection of the current forces the river to withdraw suddenly from some banks by the formation of sand bars. The sand bars appear up and down stream from the cause of deflection. In many instances their formation can be definitely anticipated and located. The addition of successive sand bars is at times of excessive floods. Other islands, portions of the flood plain, are often severed at flood season by new short-cut channels. The sand-bar and flood-plain islands have invariably been a source of trouble and expense in river navigation. It is possible that having in mind the controls which cause the departure of the current of a river, we may foresee where the islands will form along our rivers and thereby simplify navigation.

This process of lateral swinging due to a deflection of the current from the normal curves is recognized by the formation of sand-bar

islands and may be called the partition process. The result is the partition plain, likewise sloping toward the river, but undulating, with elevations representing the island walls which successively parted the river, and with intervening channels representing the abandoned courses of the river. And furthermore, it may be said, in consideration of the four processes which account for the lateral swinging of a river, that while the short-cut and the cut-off processes stop deposition at certain places to allow it to begin elsewhere, the other two processes are constructive, depositing the meander-built plain and the partition plain. The meander-built plains have long been recognized as the ordinary flood plains, although many so classified are in reality undulating partition plains. The partition plains are of frequent occurrence and are typically represented along our New England rivers. Doubtless every meandering river is swinging in some portion of its course by the partition process.

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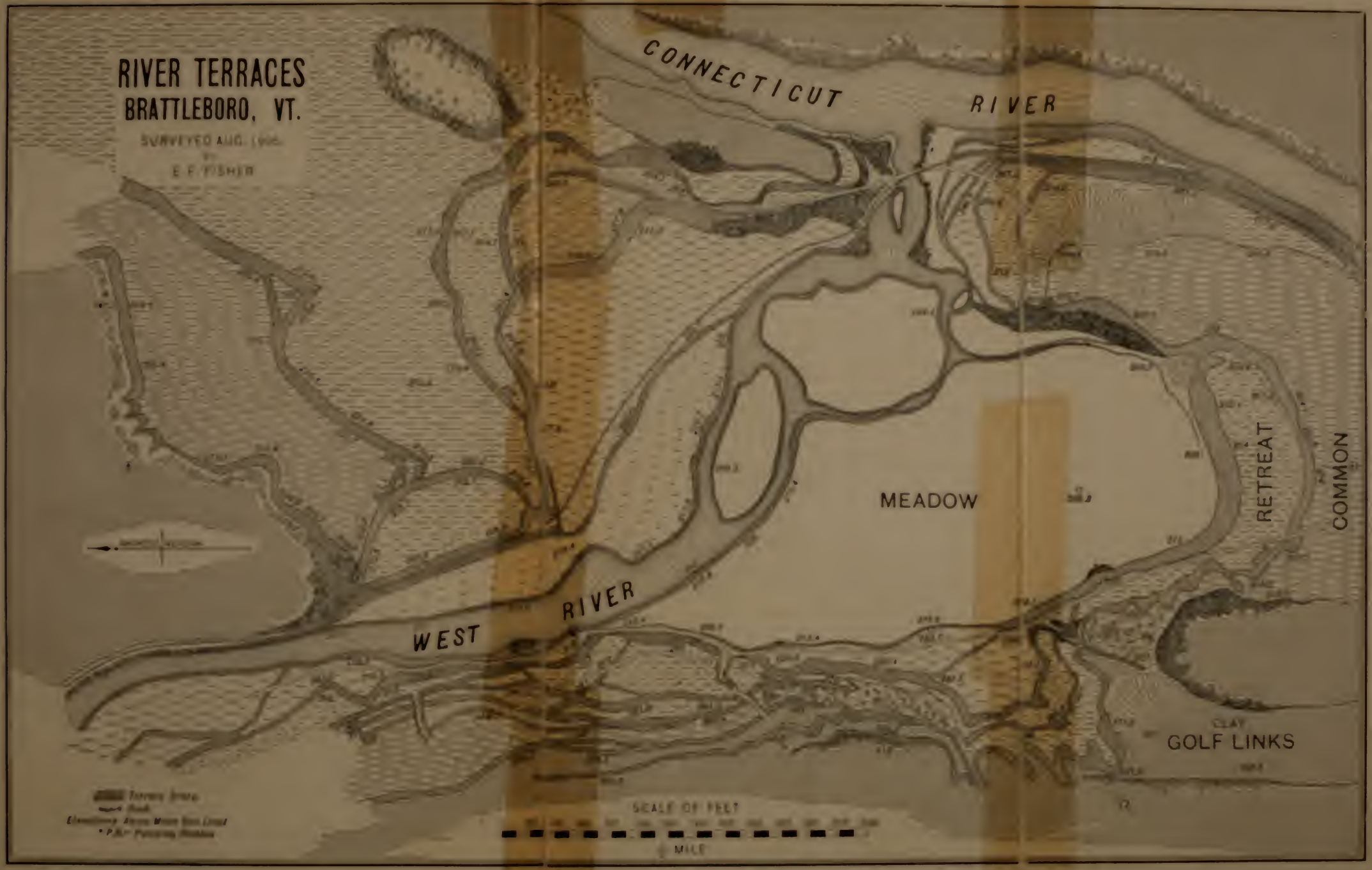

RIVER TERRACES
BRATTLEBORO, VT.
SURVEYED AUG. 1906
BY
E. F. FISHER
CONNECTICUT RIVER
MEADOW
RETREAT
COMMON
WEST RIVER
CLAY
GOLF LINKS
SCALE OF FEET
MILE

PLATE 2.

Profiles of West River terraces.

Sections made from survey map (plate 1). Show that terraces left after the river has swung several times across its valley will vary in width, and that they stand as remnants of the flood plains. Also they show that the lateral swinging of the meandering channel is very much faster than the degradation of the valley floor.

The ideal profile, showing terrace levels along the lines A–B and C–D, demonstrates that high scarps are the sum of two or more lower scarps. They are produced when the river swings more widely, undercutting the lower terrace plains.

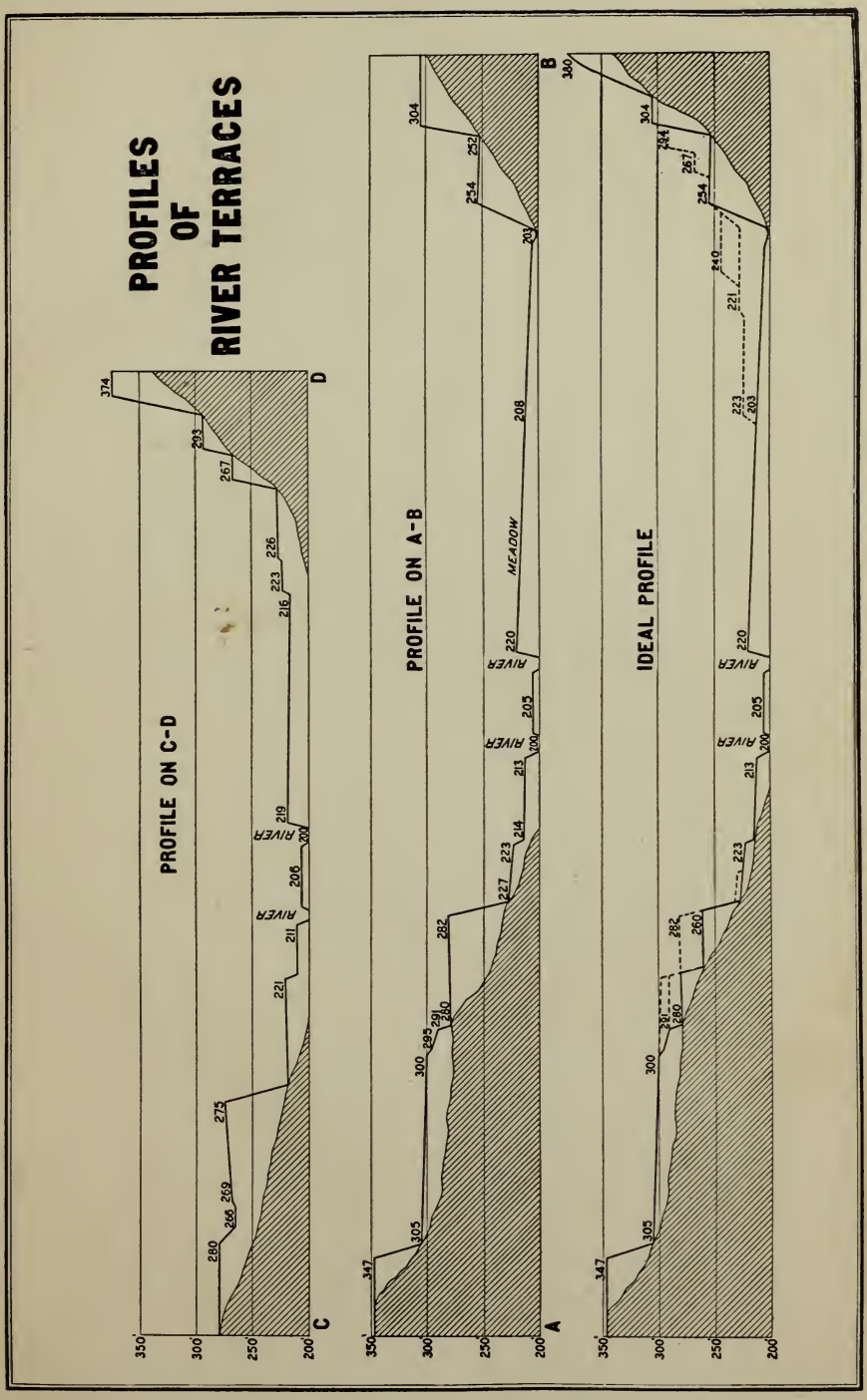
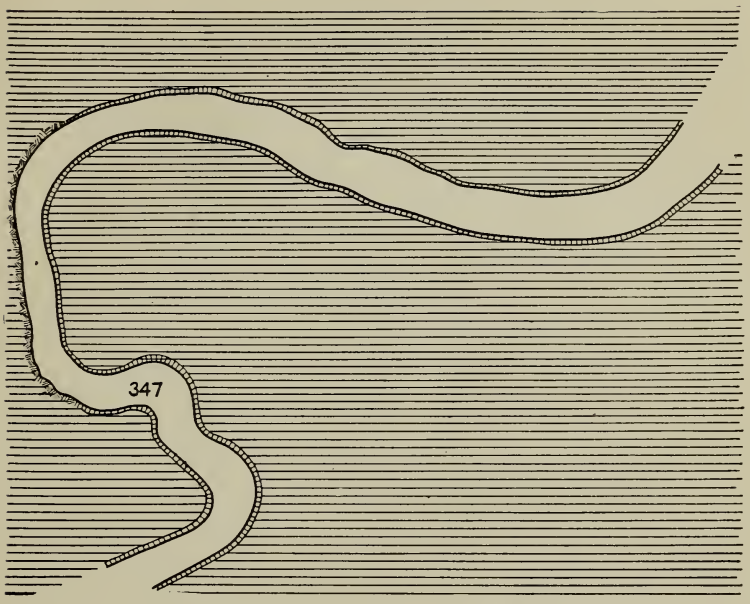

PROFILES
OF
RIVER TERRACES
PROFILE ON C-D
PROFILE ON A-B
IDEAL PROFILE
MEADOW
RIVER
C
D
A
B
350
300
250
200

PLATE 3.

Various left-hand swings of the West River since the ice age.

Figs. 1, 2, represent three (more or less hypothetical) positions of the river in the early stage of terrace pattern.



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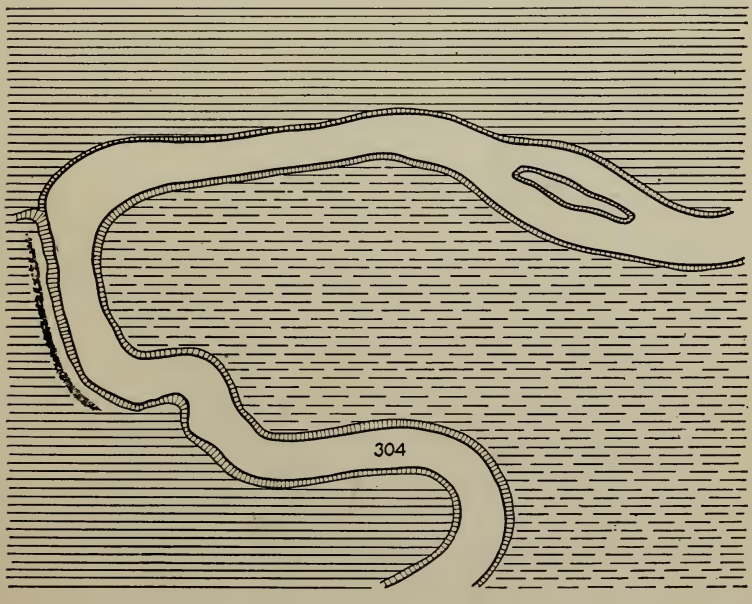

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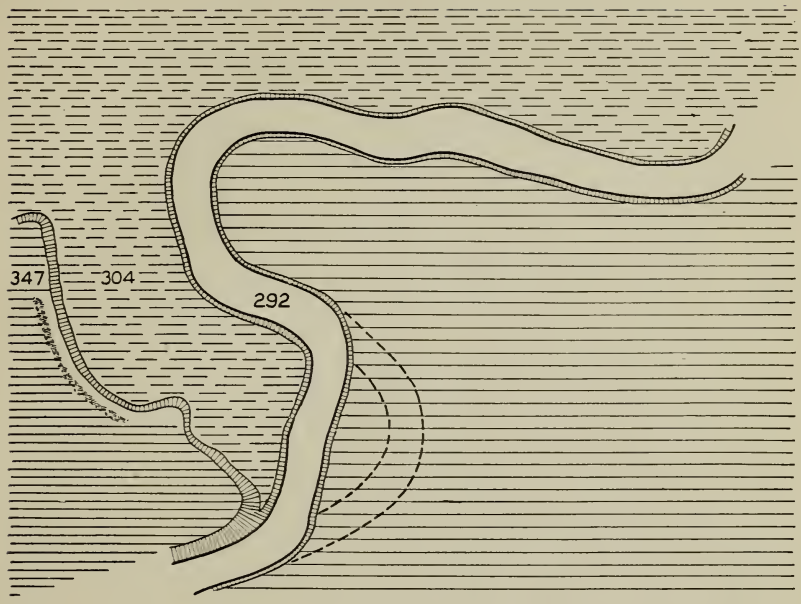
PLATE 4.

Various left-hand swings of the West River since the ice age.

Fig. 3 (like figures 1 and 2) represents a more or less hypothetical position of the river in the early stage of terrace pattern.

Fig. 4 represents a later swing of the river, showing compressed meanders. Positions of the river have been located by the existing scarps. Elevations above mean sea level. Dotted lines represent possible changes in the course of the river.



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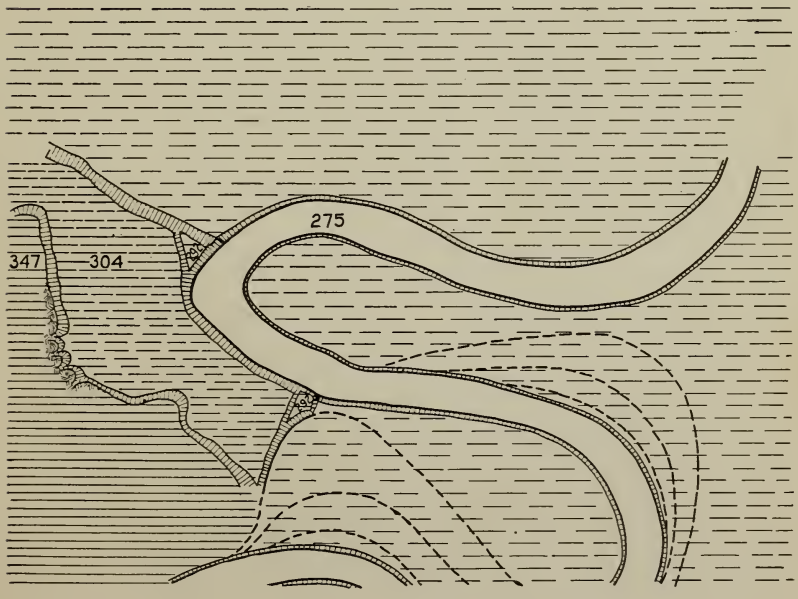

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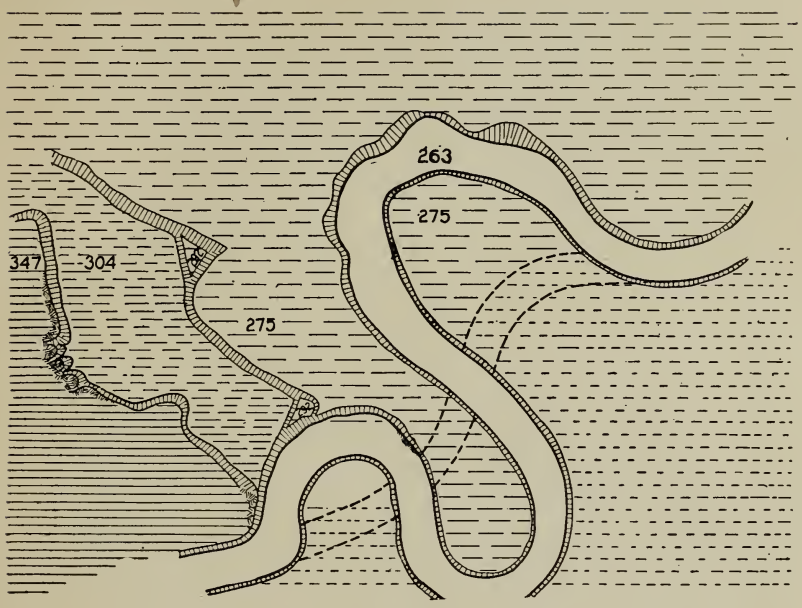
PLATE 5.

Various left-hand swings of the West River since the ice age.

Fig. 5 shows two deeply compressed meanders enforced by the rock barriers on the down-stream side of each bend. River was suddenly withdrawn from the larger bend by cut-off or short-cut, leaving a very definite river channel.

Fig. 6. Same rock controls prevented the river at the 225-foot level from eroding further to the left.



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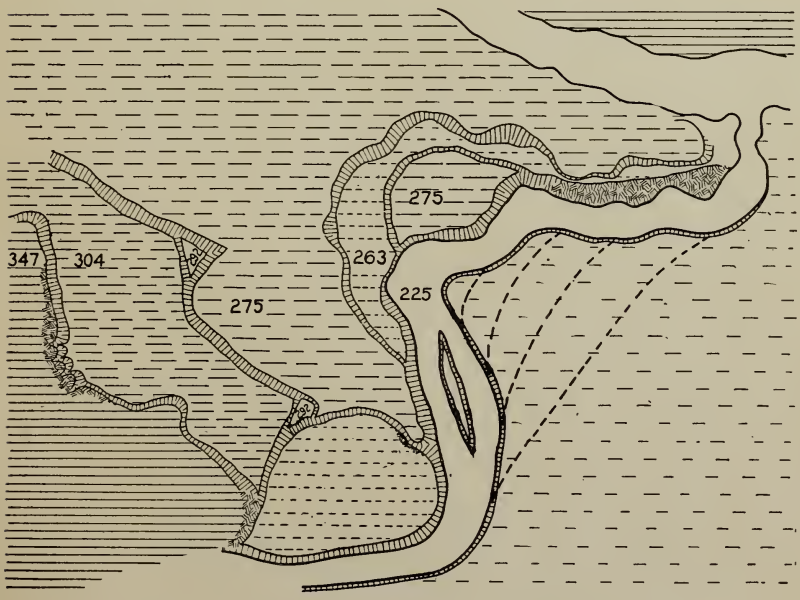

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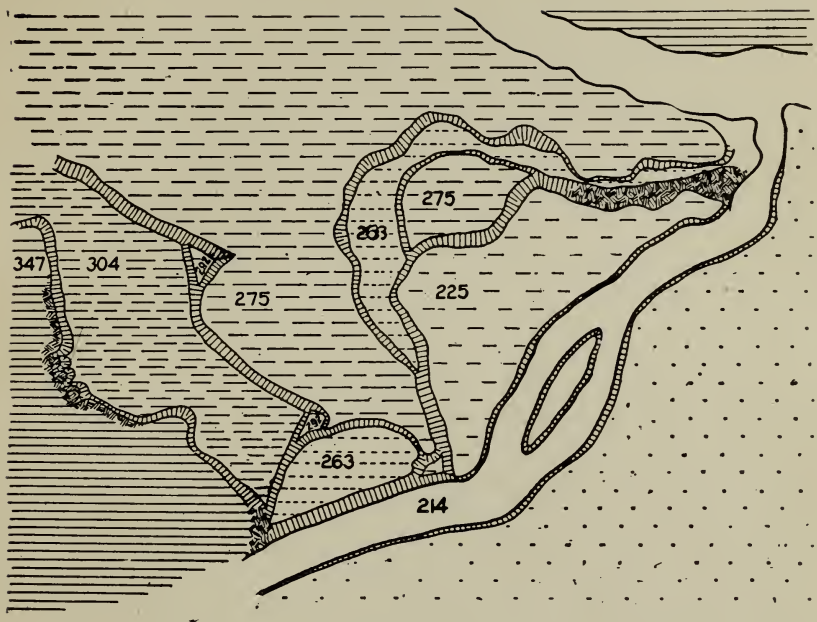
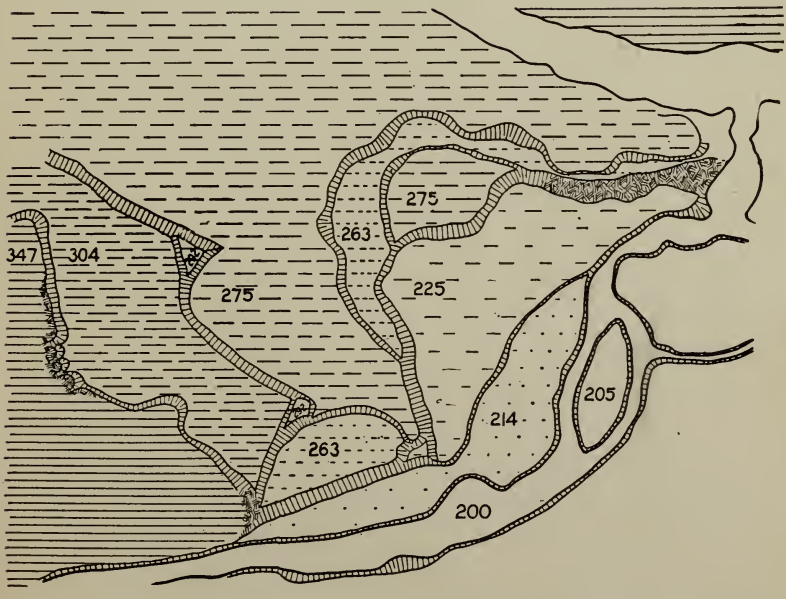
PLATE 6.

Fig. 7. Position determined by rock controls. River moving to the right by the partition process.

Fig. 8. Represents the typical middle stage of terrace pattern produced by the seven earlier swings. River is again swinging to the right by the partition process.


275
263
347
304
275
225
263
214

7


275
263
347
304
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225
205
214
263
200

8

PLATE 7.

Plates 7, 8, 9 show that the West River, during the later stages of its degrading, has swung between nodes determined by rock barriers at the Pumping station and at the junction of the West River with the Connecticut. The right-hand swinging has been, in general, accomplished by the partition process, and the left-hand swinging by the more direct short-cut process.

Plate 7 illustrates the possible terrace pattern of the West River valley at the time when the river made the left-hand swing at the 225–217-foot level.

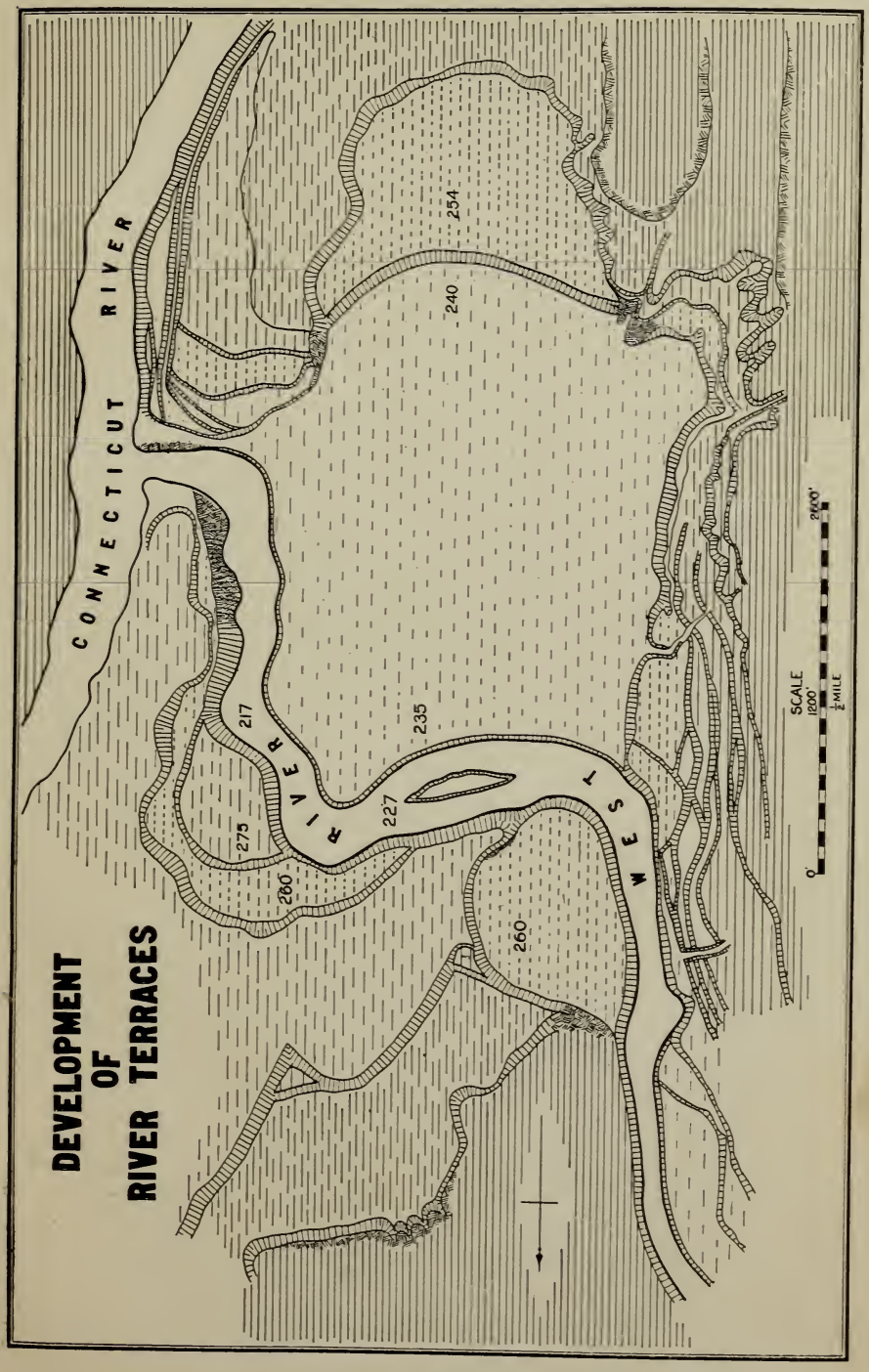
DEVELOPMENT
OF
RIVER TERRACES
CONNECTICUT RIVER
WEST RIVER
217
227
235
240
254
260
275
280
SCALE
1200'
2400'
0'
½ MILE

PLATE 8.

As the West River swung to the right from the 225–217-foot left-hand position, it made the possible 240-foot scarp, a position from which it was withdrawn by short-cut to the above left-hand 214-foot level, shown on this plate.

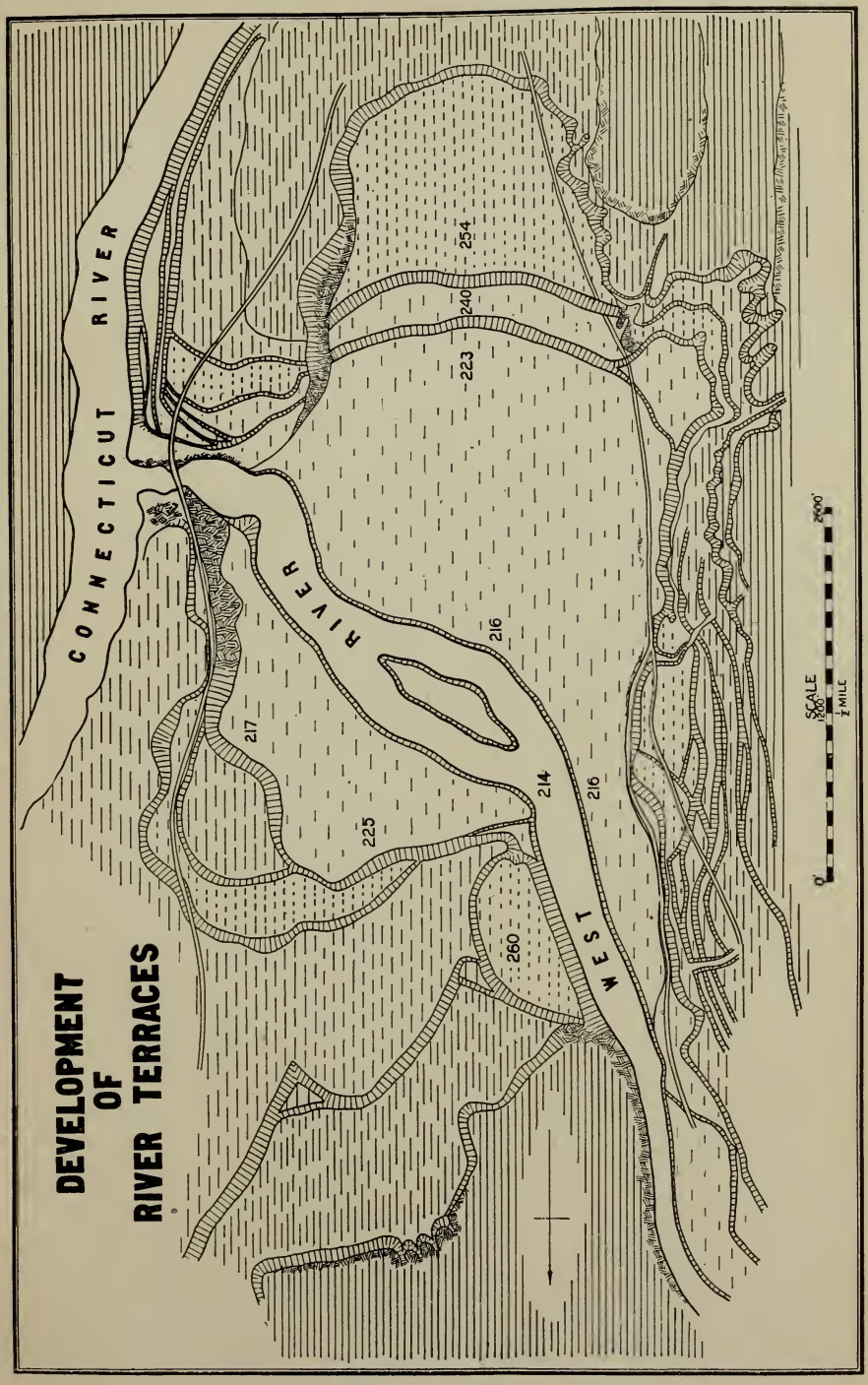
DEVELOPMENT
OF
RIVER TERRACES
CONNECTICUT RIVER
WEST RIVER
254
240
223
216
217
225
214
216
260
SCALE
2500'
0'
½ MILE

PLATE 9.

From the 214-foot level (plate 8) the West River moved by the partition process to the 203-foot level at the base of the Retreat scarp shown on this plate. By short-cut the river was withdrawn to its present position shown on plate 1, and it is again moving to the right by the partition process.

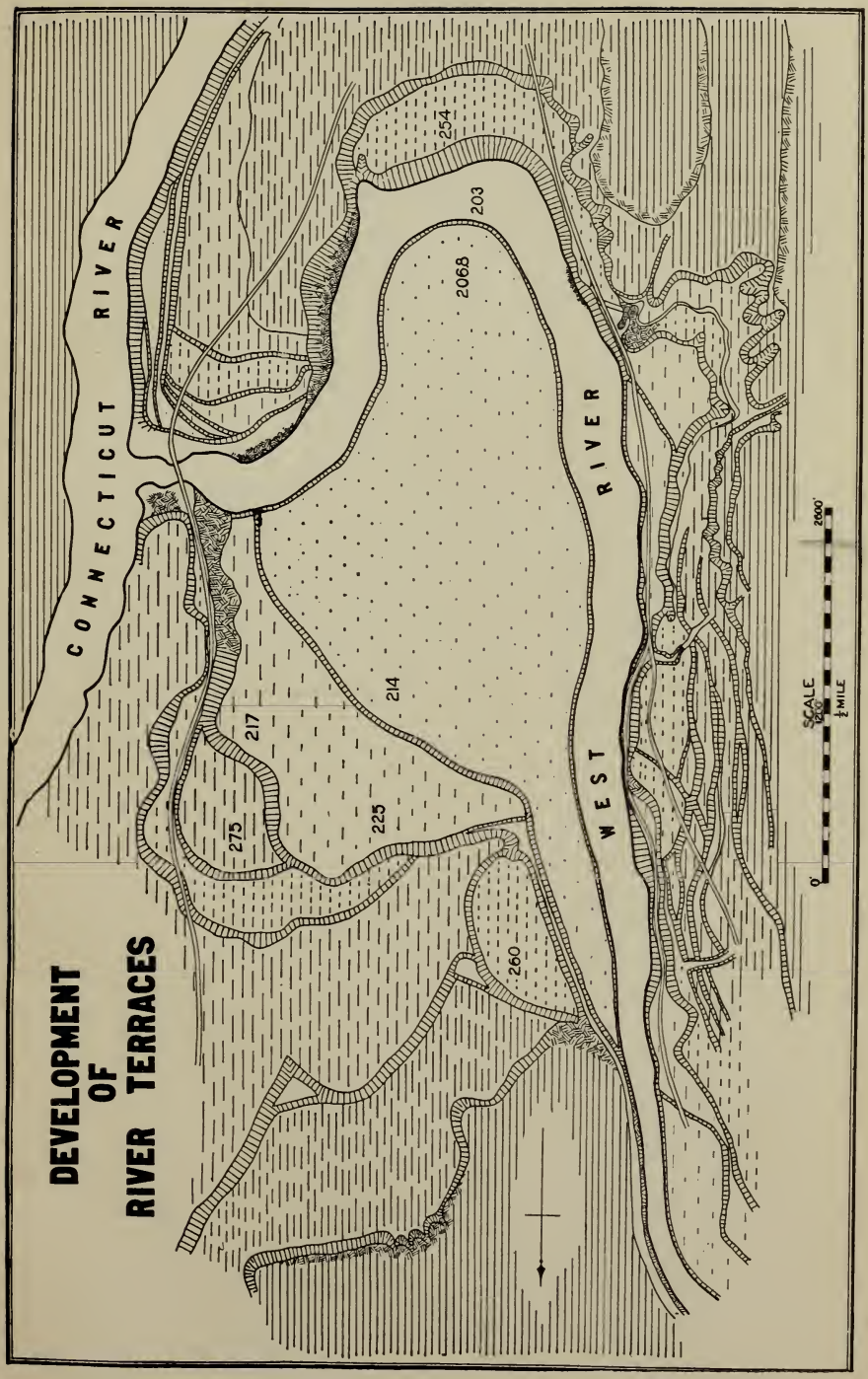
DEVELOPMENT
OF
RIVER TERRACES
CONNECTICUT RIVER
WEST RIVER
254
203
2068
214
217
275
225
260
SCALE
2000'
0'
1 MILE

PLATE 10.

Canoe Brook crossed by Putney road, seven miles from Brattleboro, Vt. Illustration of early stage of partition process in which the brook is increasing its meander. The current, deflected to the right, is adjusting itself to a new series of curves. Rapid withdrawal from the left bank has resulted in the sand-bar island. The river is parted thereby, and in time the right channel will acquire the whole stream.

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PLATE 11.

Fig. 1. Illustration of middle stage of partition process in which the brook has withdrawn from a left-hand meander. The partition plain shows four ridges (former islands) separated by valleys (former channels).

Fig. 2. Illustration showing undulations of a young partition plain. The elevations represent the island walls which successively parted the river, and the intervening channels represent the abandoned courses of the river.

1

2

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